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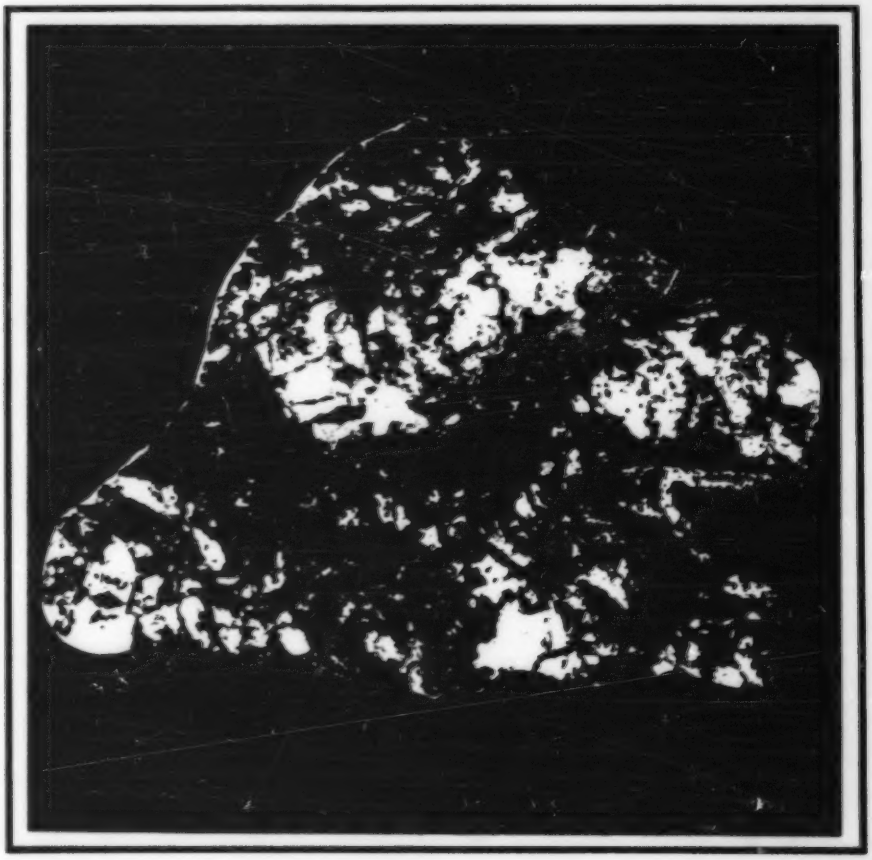
Characteristics and Tectonic Setting of Granitoid-related Mineral Deposits in New Brunswick

A.A. Ruitenberg
and L. R. Fyffe



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Cover:
Wolframite- and molybdenite-bearing breccia from the Mount Pleasant area of southwestern New Brunswick

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Mineral Resources
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Province of New Brunswick

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Minister of State for Mines

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CHARACTERISTICS AND TECTONIC SETTING OF GRANITOID-RELATED MINERAL DEPOSITS IN NEW BRUNSWICK

ABSTRACT

This report compares several distinct types of mineral deposits in New Brunswick associated with different families of granitoid rocks that were largely emplaced during the later stages of terrane accretion in the Appalachian system. Contact metasomatic and vein type base metal sulphide deposits and porphyry copper-molybdenum deposits are related to subvolcanic Ordovician and Silurian-Devonian calc-alkaline intrusions with I-type characteristics. Small amounts of scheelite and gold are also common in these deposits. The subvolcanic intrusions contain a significant mantle-derived component. Antimony-gold, tungsten-molybdenum, and base metal vein deposits are related to Late Silurian to Early Devonian bimodal batholiths with mixed S- and I-type affinities. These batholiths probably formed in large part from partial melting of a thick Cambrian-Ordovician continental rise prism and underlying Avalon continental basement. The most extensive tungsten, molybdenum, and tin deposits are associated with Middle to Late Devonian silica-rich granites with A-type features. These intrusions may have been derived from melting of previously dehydrated continental crust and emplaced at relatively shallow depth; some, such as those at Mount Pleasant, are associated with terrestrial subvolcanic complexes.

RÉSUMÉ

Ce rapport compare divers types de gîtes minéraux associés aux différentes familles de roches granitiques qui se mirent en place durant des stades tardifs d'accrétion de terranes du système Appalachien du Nouveau-Brunswick. Des intrusions sous-volcaniques d'âge Ordovicien et Siluro-Dévonien avec des caractéristiques de type-I sont accompagnées de métasomatisme de contact avec des gîtes de métaux de base filoniens et de cuivre-molybdène porphyrique. De petites quantités de scheelite et d'or sont aussi communes dans ces dépôts. Les intrusions sous-volcaniques sont dérivées en grande partie du manteau. Les gîtes d'antimoine-or, tungstène-molybdène et de métaux de base filoniens sont associés à des batholites bimodaux d'affinités de type-S et -I. Ces batholites se formèrent probablement en grande partie par fusion partielle d'un prisme épais du glacis continental, d'âge Cambro-Ordovicien, et du socle continental d'Avalon sous-jacent. Les gîtes de tungstène, molybdène et

d'étain les plus importants sont associés à des granites d'âge Dévonien moyen à supérieur qui sont riches en silice et présentent des affinités de type-A. Ces intrusions peuvent être dérivées par fusion partielle d'une croûte continentale, déjà déshydratée, et mises en place relativement près dela surface; certains gîtes, comme ceux de Mount Pleasant, sont associés à des complexes sous-volcaniques terrestres.

INTRODUCTION

Several distinct types of mineral deposits occur in the New Brunswick Appalachians in and near plutons that ranging in age from Early Ordovician to Late Devonian (Ruitenberg and Fyffe 1982). These plutons were emplaced in several tectonostratigraphic terranes during distinct stages of tectonic development. The characteristics of the plutons and associated deposits, and their relationship to tectonic evolution are described in this report. The designation of tectonostratigraphic terranes is taken from Fyffe and Fricker (1987) with minor modifications.

TECTONIC SETTING

Extensive granitoid batholiths with associated mineral deposits are concentrated in the Cambro-Ordovician Miramichi and St. Croix terranes. Several small granitoid stocks and associated deposits are found in the Upper Ordovician to Devonian Matapédia Belt to the northwest of the Miramichi Terrane. Detailed descriptions of the tectonostratigraphic subdivisions in New Brunswick and their accretionary history are given, respectively, in Ruitenberg et al. (1977), Fyffe and Fricker (1987), and van Staal and Fyffe (in press), and only a brief summary is given here.

The Elmtree Terrane of New Brunswick is divided into the Fournier and Elmtree groups within an inlier in the Pointe Verte area to the northwest of Bathurst in northern New Brunswick (Figure 1). The Early Ordovician Fournier Group is in the thrust contact with the Elmtree Group to the south (van Staal and Fyffe, in press). The Fournier Group is an ophiolitic complex mainly composed of intensely deformed gabbro that is enveloped by pillow basalts and feldspathic wacke (Pajari et al. 1977; Rast and Stringer 1980). The Elmtree Group is characterized by intensely folded Ordovician quartz wacke and slate. The Elmtree Terrane can be correlated with the Dunnage Zone of Newfoundland (Rast et al. 1976a), The Elmtree Terrane (Figure 1) is unconformably overlain by Early Silurian conglomerate of the Matapédia Belt. Basinward, the Matapédia Belt contains Upper Ordovician clastic turbidites of the Grog Brook Group and is conformably overlying Upper Ordovician to Lower Silurian argillaceous limestone of the Matapédia Group (St. Peter 1978). The Matapédia Group is conformably overlain by shallow marine sedimentary and volcanic rocks of the Silurian Chaleurs and Devonian Tobique and Dalhousie groups. Many subvolcanic stocks intrude the Silurian-Devonian volcanic succession. Lead isotope signatures from these intrusions are distinctly less radiogenic than those from the

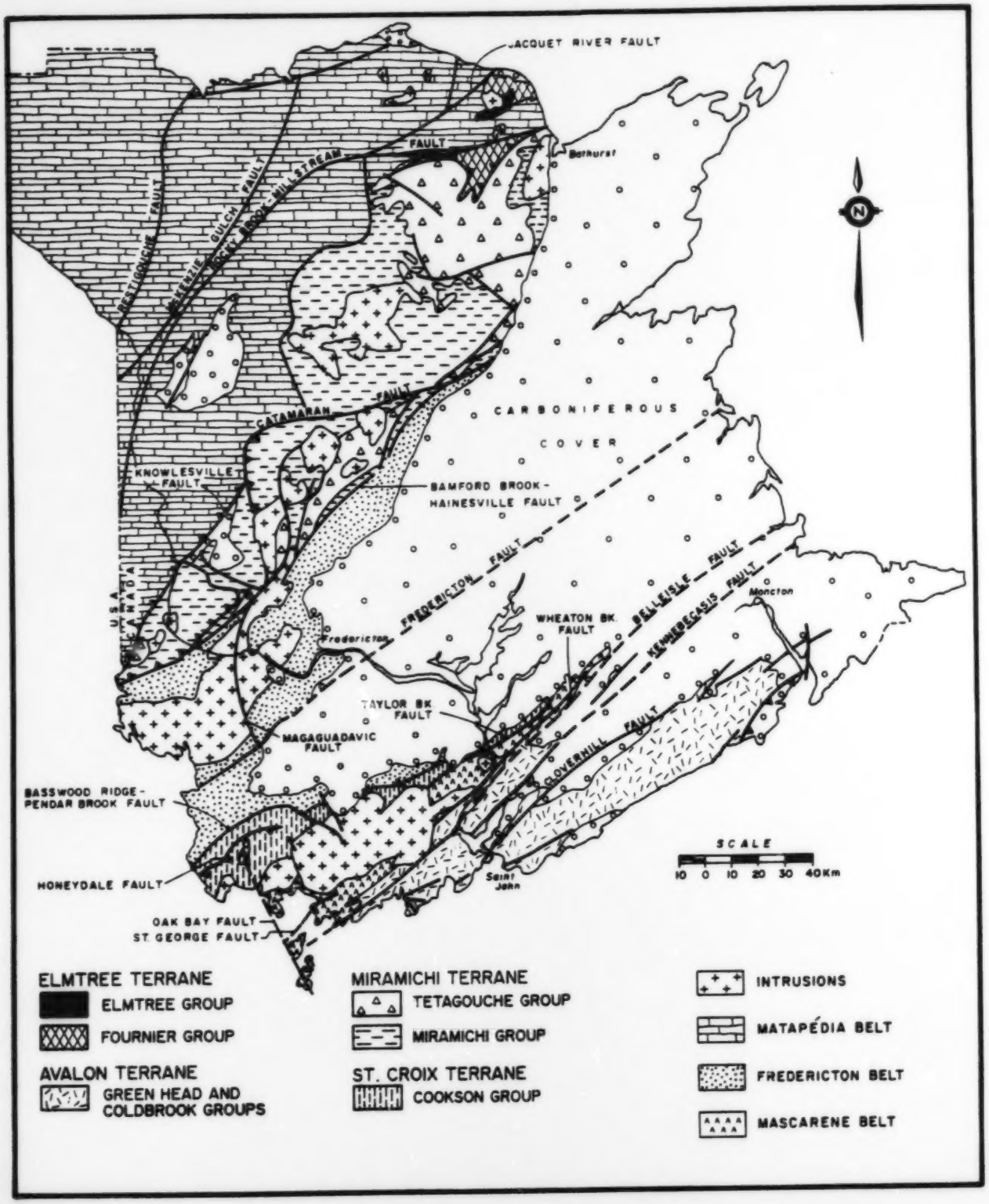


Figure 1. Map showing the tectonostratigraphic divisions of New Brunswick.

Miramichi Terrane to the southeast (Ayuso and Bevier 1991).

The Miramichi Terrane of central and northern New Brunswick is composed of Cambrian-Lower Ordovician quartz wacke and slate of the Miramichi Group and strongly resembles the Gander Group of Newfoundland. Abundant plutons of Ordovician granite emplaced within the Miramichi Group are co-magmatic with volcanic rocks of the Tetagouche Group (Fyffe et al. 1988; Whalen 1983, 1988). The Miramichi Group is conformably to disconformably overlain by the Tetagouche Group - a bimodal suite of rhyolitic and basaltic volcanic rocks with intercalated chert, iron formation, lithic wackes, and minor limestone. Large stratiform base metal sulphide deposits are associated with the felsic volcanic complex of the Bathurst area. The chemistry of these rocks (Davies et al. 1973; Whitehead and Goodfellow 1978; van Staal 1987) suggests that the complex represents a back-arc intracontinental volcanic sequence that formed along the southern margin of the back-arc oceanic basin, represented by the Elmtree Terrane. Thrusting and folding associated with closure of this basin during the Late Ordovician and Early Silurian produced the penetrative fabric in these rocks (van Staal 1987). A subduction-related volcanic sequence occurs in the southwestern Miramichi Terrane near Woodstock (Dostal 1989).

The St. Croix Terrane, represented by the Lower to Middle Ordovician Cookson Group (Ruitenberg and Ludman 1978; Ludman 1987; Fyffe and Riva 1991), consists of graphitic slates that grade upward into a sequence of quartzite and slate. The Cookson Group is unconformably overlain to the southeast by Silurian conglomerate and sandstone that contain a shallow-water brachiopod fauna. The Cookson and Miramichi groups are interpreted as sequences of continental rise sedimentary rocks that were deposited on thinned continental crust off the Avalon margin (Rast et al. 1976a, b; Ruitenberg et al. 1977). The Fredericton Fault, a major wrench fault that cuts across Silurian turbidites of the Fredericton Belt, is considered the boundary between the Miramichi and St. Croix terranes. Its extension into Maine, the Norumbega Fault, dextrally displaces Devonian granite (Fyffe and Fricker 1987). The Basswood Ridge-Pendar Brook Fault, which constitutes the southern boundary between the Fredericton Belt and the St. Croix Terrane, is truncated by the Devonian Saint George Batholith (McCutcheon 1987; Fyffe and Riva 1990).

The oldest rocks in the Caledonia Highlands of the Avalon Terrane (Figure 1) are intensely deformed, calcareous, and quartzitic metasedimentary rocks of the Neohelikian Green Head Group (Hoffman 1974). The Coldbrook Group, which is in fault contact with the Green Head Group, is composed of Hadrynian mafic and felsic volcanic rocks and intercalated metasedimentary rocks. The bimodal Coldbrook volcanic sequence and associated subvolcanic plutons may be related to an intracratonic rift zone that formed during the early opening stages of the Paleozoic Iapetus Ocean (Giles and Ruitenberg 1977). An alternative model, supported by Rast et al. (1976a, b) and Dostal and McCutcheon (1990), interprets the Coldbrook Group as a continental margin volcanic arc. Cambrian-Lower Ordovician quartzite, sandstone, and shale of the Saint John Group and Upper Devonian-Carboniferous fluviatile and deltaic sedimentary rocks overlie parts of the Avalon Terrane. Silurian to Lower Devonian volcanic and sedimentary rocks of the Mascarene Belt extend along the northwestern boundary of the Avalon Terrane. Currie (1988a, b) and

McLeod and Rast (1988) have identified similar rocks within the Avalon Terrane and have interpreted them to unconformably overlie the Coldbrook Group. Thomas and Willis (1989) have suggested, on the basis of gravity data, that Avalonian basement extends to the northwest of the Belleisle Fault beneath the Mascarene Belt.

Late Silurian to Early Devonian continental collision generated abundant biotite and muscovite-biotite granites and associated mafic intrusions in the Miramichi and St. Croix terranes of New Brunswick where the continental crust became thickened by extensive thrusting, wrench faulting, and associated folding (Fyffe et al. 1981). The granitoids in these bimodal suites are generally metaluminous to slightly peraluminous and have characteristics of I-type granitoids derived from igneous source areas (Whalen 1987, 1988). Some highly peraluminous, cordierite-bearing granites with S-type affinities, considered to be derived from sedimentary source areas (Chappell and White 1974), are associated with the I-type plutons.

In contrast with the bimodal batholithic suites in the Miramichi and St. Croix terranes, typical high-level calc-alkaline stocks were emplaced in the Matapédia Belt and locally in the southwestern Miramichi Terrane and Mascarene Belt. Comagmatic volcanic rocks in the Matapédia Belt have been interpreted to have been generated in a strike-slip regime during continental convergence (Dostal et al. 1988).

Devonian peralkaline and silica-rich granites with some A-type features were emplaced at shallow depth in parts of the Miramichi and St. Croix terranes. These intrusions cut across penetrative tectonic fabrics (Ruitenberg 1967) and their emplacement probably postdated continental collision (McLeod 1990).

DEPOSITS RELATED TO CALC-ALKALINE SUBVOLCANIC INTRUSIONS

Numerous lead, zinc, and copper sulphide deposits are associated with high-level, intermediate to felsic intrusions within Upper Ordovician-Devonian rocks of the Matapédia Belt of northwestern New Brunswick, and locally in the Mascarene Belt of southern New Brunswick. Three types of deposits are associated with these intrusions: contact-metasomatic base metal sulphide, vein-type base metal sulphide, and porphyry copper-molybdenum deposits (Figure 2, Table 1). Small amounts of gold commonly occur with these deposits.

Petrological and petrochemical studies (Ruitenberg and Fyffe 1982, 1983) of the high-level intermediate to felsic intrusions emplaced in the Matapédia Belt have shown that these intrusions have a considerable range of SiO_2 content and contain abundant intermediate rocks with hornblende rather than biotite as the characteristic accessory mineral; K_2O/Na_2O and Rb/Sr ratios are also relatively low. These features are typical of calc-alkaline magmas derived from an igneous source area (I-type characteristics) and may indicate that the Matapédia Belt is underlain, at least in part, by back-arc oceanic substrate (Fyffe and Fricker 1987).

Contact Metasomatic Base Metal Deposits

A large number of contact metasomatic deposits are associated with small stocks of mainly intermediate composition that cut calcareous sedimentary rocks in the Matapédia Belt. The number assigned to each deposit, in parenthesis in the following text, is shown in Figure 2 and Table 1.

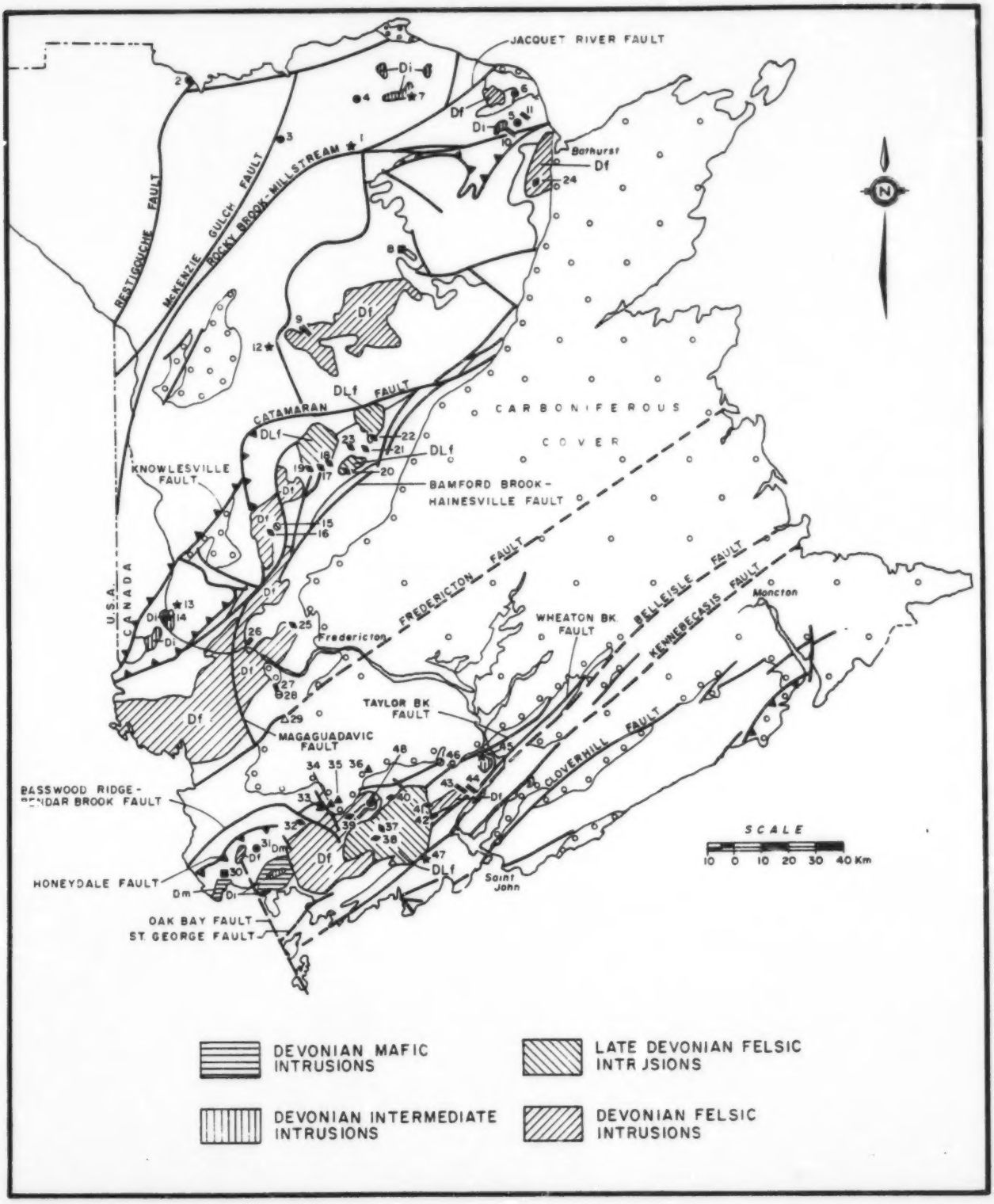


Figure 2. Map showing distribution of plutonic-related deposits in New Brunswick. (See Table 1 for names of numbered deposits shown.)

TABLE 1. Mineral Deposits Related to Various Granitoid Intrusions in New Brunswick

AGE OF INTRUSIONS	INTRUSIONS	TECTONOSTRATIGRAPHIC ZONES			
		MATAPEDIA BELT NW MIRAMICHI	SE MIRAMICHI AND NW ST. CROIX SUBZONES	SE ST. CROIX SUBZONE	CALEDONIA SUBZONE
CARBONIFEROUS	rhyolitic subvolcanic intrusions		△ U in fractures and breccia related to to volcanic centres 29. Harvey	▲ W, Sn, Mo, F +/-Cu +/-Zn +/-Pb in fractured and brecciated sub-volcanic intrusions 33. True Hill 34. Mount Pleasant 35. Mud Lake 36. McNamara Prospect	
LATE DEVONIAN – EARLY CARBONIFEROUS	quartz-feldspar porphyry and biotite +/- muscovite granite	// Zn, Pb, Cu, Ag, Mo, U in quartz veins and stringers related to dykes in fractured zones 9. Long Lake			
			◆ W, Sn, Mo, F, Be +/-Cu, Pb, Zn in greisen- and related endogranitic veins and disseminations 16. Sisson Brook 17. Burnthill 18. Tin Hill 19. Two and a Half Mile Brook 20. Todd Mountain 21. Falls Brook and Rocky Brook 22. Little Dungarvon 23. Sisters Brook	◆ W, Sn, Mo, F, Be, +/-Cu, Pb, Zn in quartz and greisen veins 37. Mistake Lake 38. Victoria Lake 39. Deer Lake 40. Howard Mountain 41. Square Lake 32. Pleasant Ridge ■ Sn, Cu, Zn, Pb, in skarns 42. Nerepis	
EARLY – MIDDLE DEVONIAN	muscovite-biotite granite, biotite +/- hornblende granite, riebeckite granite, syenite		◆ W, Mo, F +/-Cu +/-Pb, +/-Zn in quartz veins and stringers 24. Pabineau Lake 25. Zealand Station	// Zn, Pb, Cu in carbonate and quartz veins 43. Reserve Brook 44. Johnson Croft	
	granodiorite, quartz diorite, granite	★ Cu +/-Mo +/-Pb +/-Zn +/-Au in fractured porphyry stocks 1. Upsalquitch Forks 7. Benjamin River 12. Mount Costigan 13. Connell Mountain 14. Bulls Creek - Cobbler Sexton		★ Cu, Mo in fractured porphyry intrusions 45. Evandale	★ Cu +/-Mo in fractured porphyry 47. Eagle Lake
		// Zn, Pb, Cu +/-Au in carbonate +/- quartz veins associated with dykes 10. Nicholas Denys 11. Nigadoo River			
			⊖ Sb, Au, +/-Cu +/-Pb +/-Zn +/-U in quartz veins and disseminations 15. Sisson Brook 28. Lake George	⊖ Sb, Au in quartz veins 46. Pendar Brook	
		● Fe, Cu +/-Mo, W, Pb, Zn, +/-Au in contact aureoles 2. Patapedia 3. Burntland Brook 4. Popelogan 5. Beresford 6. Nadran	■ W +/-Mo +/-Au in contact aureoles 26. Coac Stream 27. Lake George Tungsten	⊗ Au in quartz veins related to granite intrusions 31. Waweig 48. Jimmy Hill and Otter Lake South	
	gabbro, norite, troctolite	■ Disseminated Fe, Ni, Cu 8. Goodwin Lake		■ Massive and disseminated Fe, Ni, Cu 30. St. Stephen	

The Patapedia deposit (2), to the southwest of the Patapedia River, is a contact metasomatic deposit that occurs in a brecciated and fractured skarn zone immediately east of a prominent north-trending wrench fault that cuts argillaceous limestone, calcareous shale, and limestone of the Upper Ordovician to Lower Silurian Matapédia Group. The calc-silicate skarn is associated with granodioritic dykes and sills. Some narrow sections (30-75 cm) grading 2.51-4.95% Cu, 2.65% Zn and 37.7-109.0 g/t Ag were intersected in drill cores. The principal sulphides in the deposit are pyrrhotite and pyrite. Chalcopyrite is associated with pyrrhotite, which is considered to have resulted from prograde metamorphism of diagenetic pyrite; sphalerite and galena occur in minor amounts (Williams-Jones 1982). Arsenopyrite is the main mineral in a breccia zone in the southern part of the deposit, but elsewhere it is fairly minor. The highest concentrations of sulphides coincide with the most intense metasomatism and with potash alteration in the dyke rocks.

A contact metamorphic base metal sulphide deposit occurs in the Burntland Brook area (3) immediately east of a prominent northeast-trending fault. Pyrrhotite, chalcopyrite, and minor molybdenite are found in a siliceous, garnetiferous skarn zone where feldspar and feldspar-quartz porphyry dykes intrude calcareous rocks of the Matapédia Group. Most intersections in drill cores are narrow and low grade, but Blecha (1968) described a 1.7 m long chip sample across one trench that assayed 9% Cu.

The Popelogan deposit (4), 25 km south of Campbellton, occurs in a skarn zone on the eastern limb of a shallow-plunging anticline within the Matapédia Group (Potter 1965). The skarn is associated with a granodiorite stock and related porphyry sills and dykes (Leslie 1963). The deposit contains pyrite, pyrrhotite, chalcopyrite, sphalerite, and minor molybdenite and scheelite as irregular veinlets and disseminations concentrated around a small apophysis of the stock. As in the Patapedia deposit, the highest grade of copper is in the quartz-diopside-pyrrhotite facies of the skarn (Quartermain 1981).

The Beresford deposit (5), located 18 km northwest of Bathurst, is an extensive contact metasomatic deposit hosted by Silurian sedimentary rocks within 800 m of the Nicholas Dénys granodiorite stock and immediately north of the east-trending Rocky Brook-Millstream dextral wrench fault (Bachinski 1969). The deposit is a discontinuous lens composed of magnetite, chalcopyrite, pyrite, sphalerite, pyrrhotite, arsenopyrite, marcasite, and molybdenite. The skarn minerals are garnet, diopside, hornblende, actinolite, muscovite, epidote, albite, and chlorite.

The Madran deposit (6), 2 km east of the Antinouri Lake Granite, comprises conformable lenses of massive to disseminated pyrite, pyrrhotite, chalcopyrite, sphalerite, silver minerals, and minor gold in a skarn zone within Ordovician sedimentary rocks of the Elmtree Group.

Base Metal Sulphide Veins

The most prominent base metal sulphide vein system, the Nigadoo River deposit (11), is located 17 km northwest of the City of Bathurst (Figure 2) within the Matapédia Belt. The metallic minerals include pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, and minor cassiterite, stannite and gold, which are hosted by northwest-trending quartz-carbonate veins in Silurian calcareous metasedimentary rocks and a quartz-

feldspar porphyry stock (Tupper et al. 1969) (Figure 3). A reconnaissance examination of the mine suggested that early mineralization occurred along penetrative cleavage surfaces deformed by an intense, northwest-trending en echelon system of cross folds. Younger northwest-trending veins transect the cross folds. Although no detailed structural study was made of the Nigadoo mine, the complex mineralized structure is consistent with dextral movement along the Rocky Brook-Millstream Fault system to the south.

Northwest-striking base metal sulphide veins (Halfmile, Pine Tree, Hachey, and Shaft deposits) associated with granodiorite porphyry intrusions are exposed in old prospecting trenches south of the Nicholas Denys stock (10) along the trace of the Rocky Brook-Millstream Fault (Davies et al. 1969).

Porphyry Copper-Molybdenum-Gold Deposits

Most porphyry copper-molybdenum-gold deposits in New Brunswick occur in the Matapédia Belt of northern New Brunswick, but a single occurrence is located within the southwestern Miramichi Terrane. None of these deposits have been fully explored and, therefore, little is known about characteristic features such as zoning and alteration.

The largest known porphyry copper-molybdenum-gold deposit in New Brunswick was discovered in the Connell Mountain stock (13) southeast of Woodstock within the Miramichi Terrane (Venugopal 1979; Thomas and Gleeson 1988). This granodiorite stock intrudes Cambro-Ordovician quartz wacke, slate, and siltstone of the Miramichi Group and is probably a cupola of the Ordovician Gibson Granodiorite (Bevier 1989) exposed farther south. Pyrite, pyrrhotite, chalcopyrite, and minor molybdenite and gold occur as disseminations and veinlets in intensely fractured and brecciated parts of the intrusion. Argillic and phyllic alteration are associated with the mineralized zone, which averages 0.26% Cu (Lockhart 1970). Other occurrences of this type, such as the Bulls Creek and Cobbler-Sexton deposits (14), have been found along the margin of the Gibson Granodiorite (Anderson 1968). Galena and sphalerite also occur in several of these deposits.

The Benjamin River porphyry copper-molybdenum deposit (7) in northeastern New Brunswick was intermittently explored between 1968 and 1973. The Benjamin River intrusive suite is a differentiated sequence of gabbro, granodiorite, and monzogranite that intrudes mafic and felsic volcanic rocks within the Silurian Chaleurs Group of the Matapédia Belt (Stewart 1978). Pyrite, pyrrhotite, chalcopyrite, bornite, tetrahedrite, sphalerite, and minor molybdenite, associated with potassic, phyllic, argillic, and propylitic alteration, occur within and along the contact of the granodioritic phase (Figure 4). The deposit is estimated to contain about 21 000 000 tonnes grading 0.18% Cu and 0.01% Mo.

The Upsalquitch Forks gold prospect (1), farther to the southwest, is associated with altered Late Silurian-Early Devonian (McCutcheon and Bevier 1990) diorite and minor felsic porphyry intrusions that occur near the intersection of the Rocky Brook-Millstream and Jacket River faults. Disseminated pyrite, chalcopyrite, sphalerite, galena, and gold occur in quartz-carbonate veins in the porphyry. The best gold assay reported from a grab sample is 10.34 g/t Au. The vein material is also strongly enriched in mercury (up to 6130 ppb Hg) and bismuth (up to 723 ppb Bi) (Burton 1987; Pronk and Burton 1988; Ruitenberg et al. 1989, 1990).

A subvolcanic porphyry-type

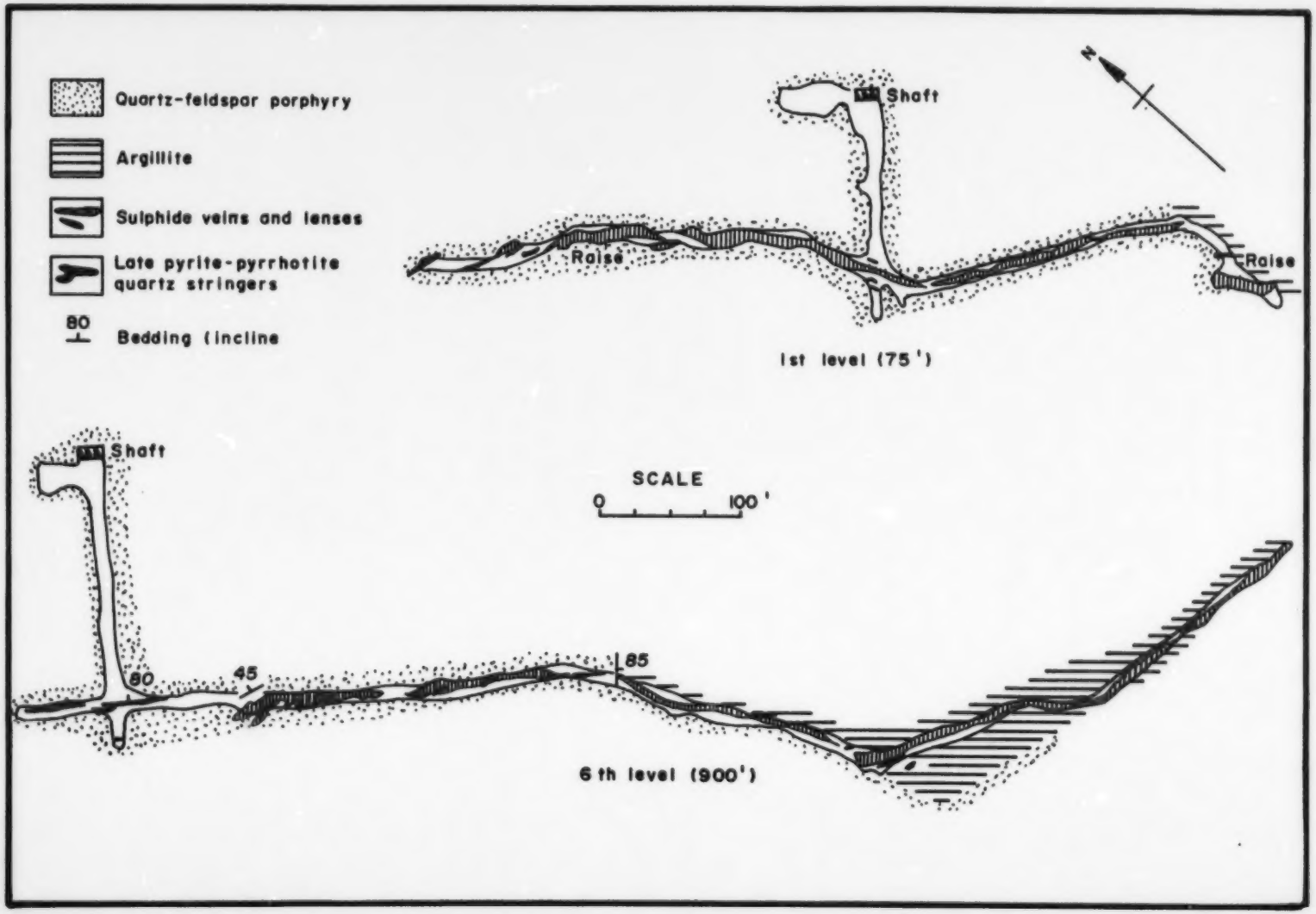


Figure 3. Geological plans of 1st and 6th levels, Nigadoo Mine (after Davies et al. 1969). See Figure 2, number 11 for location of deposit.

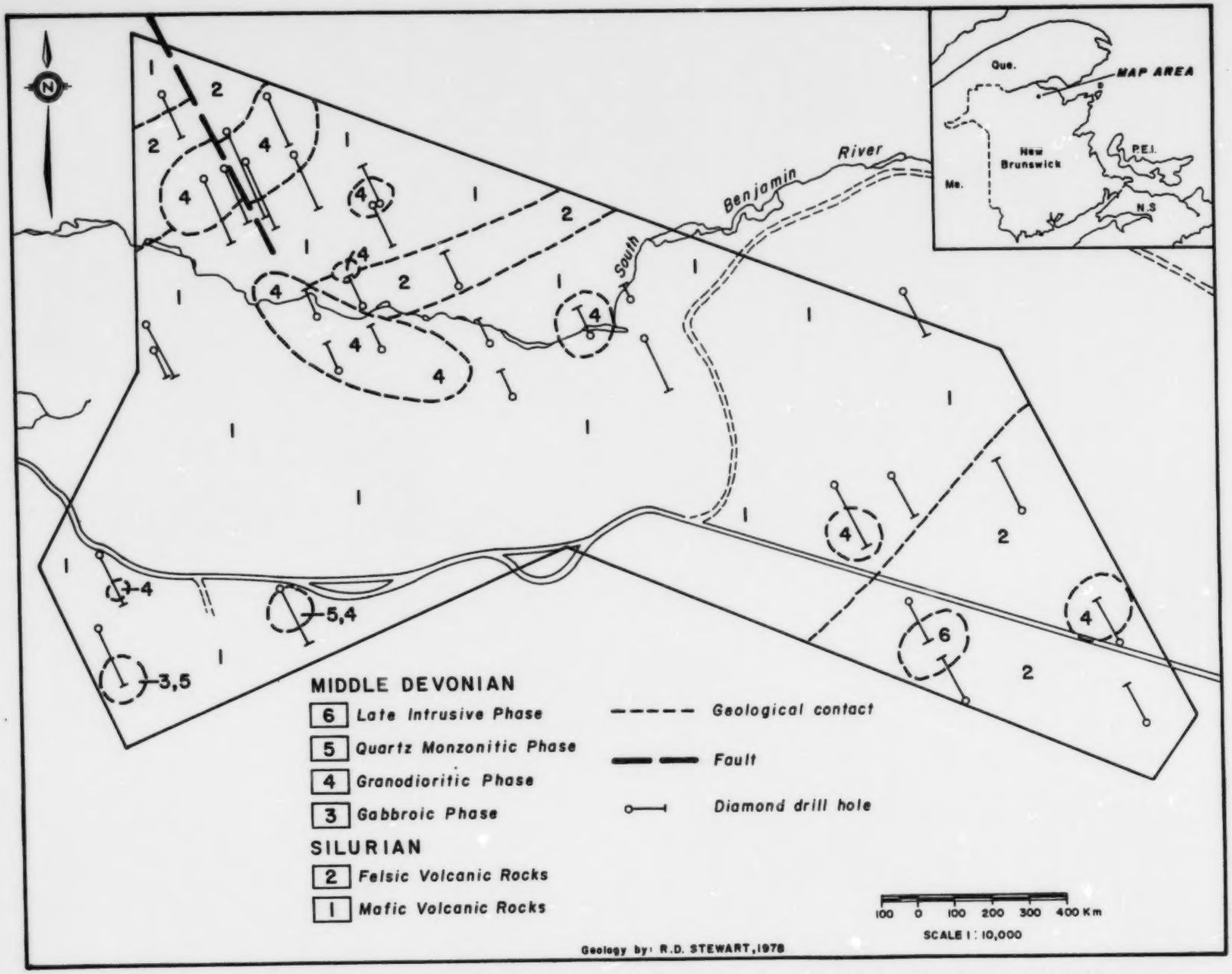


Figure 4. Geological map of Benjamin River porphyry copper deposit (after Stewart 1978).

deposit, located at Mount Costigan (12) on the southeast margin of the Matapédia Belt, is hosted by Lower Devonian felsic volcanic rocks intercalated with shallow marine sedimentary rocks. The Mount Costigan deposit forms a shallow, east-plunging breccia pipe about 200 m by 250 m in cross section (Crevier 1984; Fyffe and Pronk 1985). Pyrite, sphalerite, galena, and minor chalcopyrite occur in a stockwork of veinlets, disseminations, and breccia fillings; the metallic minerals are coarse-grained in the cavities of the breccias. Felsic flows and tuff, which surround the breccia pipe, are silicified, chloritized, and sericitized to several hundred metres from the breccia pipe. Fluorite is common throughout the altered zone, but diminishes rapidly with increasing distance from the pipe.

Economically interesting copper occurrences carrying minor gold are associated with the Eagle Lake biotite granite porphyry stock (47), which intrudes Late Precambrian-Cambrian and Silurian mafic and felsic dykes that intrude volcanic rocks of the Precambrian Coldbrook Group in the Avalon Zone (Ruitenberg 1969; Shewman 1968). The stock is composed of an equigranular core and a porphyritic phase margin that is intruded by numerous aplite dykes (Butt 1976). Sulphide-bearing quartz veins and mineralized stringers with associated phyllic and argillic alteration are confined to highly fractured parts of the intrusion. Pyrite and chalcopyrite are the most abundant metallic minerals; tetrahedrite and galena occur mostly as veinlets cutting chalcopyrite.

An extensive copper-molybdenum-gold zone is located in the northwestern part of the Devonian Evandale Stock (45), which intrudes Silurian sedimentary and volcanic rocks in the southeastern Mascarene Belt (Ruitenberg 1970; McCutcheon and Ruitenberg 1987). This stock is composed of medium-grained, equigranular to subporphyritic hornblende-bearing, biotite granodiorite and granite. Mineralized fractures and quartz stringers, carrying pyrite, chalcopyrite, molybdenite, and locally gold, are generally spaced at intervals from 2 to 25 cm apart in a zone about 500 m wide and 2700 m long. Thin aplite dykes, roughly parallel to the mineralized fractures, predate the mineralization. Phyllic alteration flanked by chlorite affected the rocks along early formed fractures; feldspar has been affected by argillic alteration along the central part of some fractures. Quartz veins with chalcopyrite, sphalerite, galena, and molybdenite occur in some fractures and locally contain varying amounts of scheelite. In addition, chalcopyrite and molybdenite are widespread as disseminations and joint coatings (D. Hattie, oral communication).

DEPOSITS RELATED TO BIMODAL BATHOLITHIC INTRUSIONS

In the Miramichi Terrane, three types of deposits are associated with gabbroic and granite batholiths with mixed I- and S-type affinities: nickel-copper sulphide deposits; base metal sulphide veins; antimony-gold and tungsten-molybdenum veins. These veins are associated, respectively, with the North Pole Stream pluton, the Pokiok Batholith, and the Nashwaak pluton.

The North Pole Stream pluton is composed principally of biotite granite with less abundant biotite-muscovite granite and minor cordierite-bearing granite and porphyritic biotite granite dykes. Lithogeochemical investigation reveals that all these phases are peraluminous and are similar to mixed I- and S-type granites (Fyffe and Pronk 1985; Whalen 1987, 1988). The biotite-muscovite granite has more SiO_2,

K_2O, Rb, Li, and less Fe, TiO_2, MnO, MgO, CaO, and Sr than the biotite granite mainly reflecting the lower biotite and lower anorthite content of plagioclase in the former. The regular decrease in the Ba to Rb ratio from biotite granite to biotite-muscovite granite through to porphyry is compatible with continuous differentiation of a single magma, but the Rb to Sr ratio first increases between the biotite granite and biotite-muscovite granite, and then decreases in the porphyry. This is consistent with the biotite-muscovite granite being a differentiate of the biotite granite, whereas the porphyry was likely derived by a separate melting event. None of the phases of the North Pole Stream pluton exhibits the extreme specialization (enrichment) in lithophile elements (Rb, Li, F, and Be) that is characteristic of the highly differentiated leucogranites associated with tin, tungsten, and uranium deposits (Strong 1980). Instead, the pluton more closely resembles those granites that gave rise to hydrothermal deposits of the so-called lithochalcophile elements (Pb, Zn, Ag, Sb, Bi, As, and Au).

Four major units of variably textured hornblende-biotite granodiorite, and biotite and biotite-muscovite granite constitute the Pokiok Batholith. Major and trace element analyses of these rocks (Lutes 1987; Ruitenberg and Fyffe 1982) show that the Pokiok also lacks the extreme differentiation and enrichment in lithophile elements. The batholith was apparently formed by partial melting of a dominant sedimentary source component mixed with variable amounts of a mantle-derived component (McCutcheon et al. 1981).

Nickel-Copper Sulphide Deposits

Nickel-copper sulphides are associated with layered mafic intrusions in the St. Stephen area (30) of the southwestern St. Croix Terrane, and the Goodwin Lake area (8) of the northeastern Miramichi Terrane. The intrusions are composed of peridotite, troctolite, olivine gabbro, anorthosite, and norite (Paktunc 1986, 1987, 1988). The St. Stephen intrusion was emplaced in a dilatant zone west of the Oak Bay sinistral wrench fault (Ruitenberg 1967; Ruitenberg and Ludman 1978). A K-Ar determination on hornblende suggests an age of emplacement of 415±19 Ma for the undeformed pluton (Wanless et al. 1973), which cuts across the penetrative fabric in the Ordovician host rocks. The deposits in the St. Stephen area (Hale 1950; Dunham 1950; Paktunc 1986, 1987) are composed of nickeliferous pyrrhotite, pentlandite and chalcopyrite in massive bodies, disseminated blebs, matrix between olivine crystals, and remobilized sulphides hosted by olivine gabbro and gabbro. About 1,000,000 tons averaging 1.03% Ni, 0.47% Cu, and 0.10% Co have been delineated (Potter 1967). Forty-two samples, analyzed by Paktunc (1987) for their platinum-group-element content, yielded up to 188 ppb Pt and 67 ppb Pd.

A large Devonian gabbroic sill in the Goodwin Lake area (8) of the northeastern Miramichi Terrane (McNutt 1962; Paktunc 1988) contains pods composed of pyrrhotite, pentlandite, chalcopyrite, and minor cobaltite and bismuthinite. One drill hole is reported to have intersected 2.3 m grading 0.88% Ni and 0.53% Cu. Maximum concentrations of platinum-group elements in 48 samples are 53 ppb Pt and 160 ppb Pd (Paktunc 1988).

Base Metal Sulphide Veins

The Long Lake deposit (9) of central New Brunswick occurs in several northwest-striking fracture

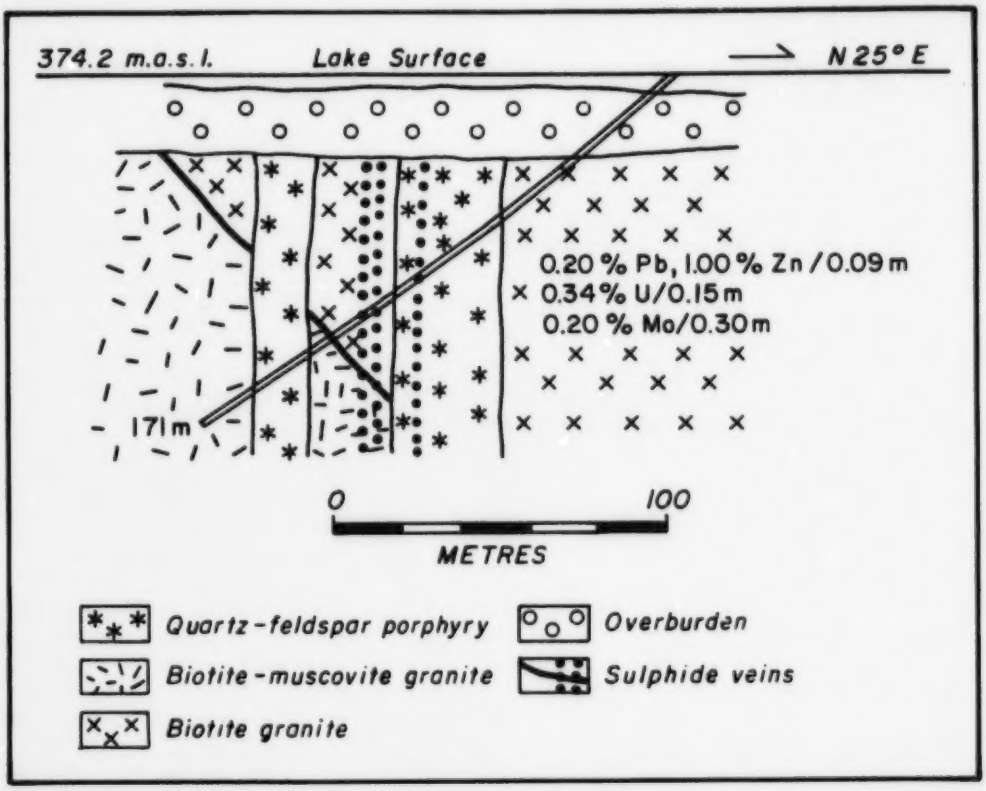


Figure 5. Section through Long Lake deposit (after Fyffe and Pronk 1985). See Figure 2, number 9 for location of deposit.

zones that cut the western lobe of the North Pole Stream pluton (Figures 2 and 5). The pluton intrudes Cambrian-Ordovician quartzose sandstone and phyllite of the Miramichi Terrane. Base metal sulphides are found in the granite and country rocks as disseminations and stringers of pyrite with minor sphalerite, chalcopyrite and galena in fractured and silicified host rocks (Hauseux and Gleeson 1980). Mineralization in the sedimentary rocks is concentrated within 600 m of the northern margin of the pluton. Veins of granite and dykes of quartz-feldspar porphyry that intruded the sedimentary rocks are also commonly enriched in sulphides. Base metal sulphides within the granite are associated with quartz veins along west-northwest-trending fracture zones. Quartz-feldspar porphyry dykes emplaced along many of these fractures tend to have metallic mineral concentrations at the contact between the dyke rock and coarser-grained biotite-granite host, which suggests that hydrothermal activity related to sulphide deposition was at least in part coeval with dyke emplacement.

Uranium and molybdenum minerals occur mainly along the southern margin of the western lobe within poorly exposed silicified granite breccia hosted by biotite-muscovite granite. A west-northwest-trending fault zone extending along the axis of Long Lake apparently acted as a channel for the uranium-bearing hydrothermal fluids. Local concentrations of uranium are also found within an altered quartz-feldspar porphyry dyke to the north of the

lake where drilling has shown muscovite-bearing granite to be present within 30 m of the surface.

Antimony-Gold and Tungsten-Molybdenum Veins

The Lake George antimony-gold deposit (28) is situated southeast of the Late Silurian to Early Devonian Pokiok Batholith, which intrudes the faulted boundary between Cambrian-Ordovician sedimentary rocks of the Miramichi Terrane and Silurian turbidites of the Fredericton Belt. The deposit comprises a system of stibnite-, native-antimony-, and gold-bearing quartz veins that cut Silurian wacke and slate. A small monzogranite stock and its contact aureole are also transected by the veins. An extensive assemblage of east-trending, steep-dipping dykes of lamprophyre and diorite, and northerly trending felsic dykes also predate the ore-bearing veins. It is notable that the mafic dykes locally contain up to 1800 ppm Sb (Morrissy and Ruitenberg 1980).

Stibnite occurs as irregular-shaped lenses and veins that are mainly concentrated in gently northeast-striking flexures in the north-dipping Hibbard vein (Figure 6). The flexures occur where the vein cuts across competent beds in the vicinity of regional fold hinges. The stibnite-bearing veins and bordering thin siliceous rinds transect a broad argillic alteration zone with pyrite, pyrrhotite, arsenopyrite, and bismuthinite. A separate extensive magnetite-quartz oxidation zone also postdates the argillic alteration zone. The stibnite-bearing quartz veins locally cut across quartz-carbonate veins enveloped by greenish grey arsenopyrite-rich alteration haloes; gold is commonly associated with the arsenopyrite and, locally, bismuthinite. Gold is also associated with low-grade scheelite (27) in early quartz-chlorite veins in parts of the contact aureole of the granodiorite stock.

Detailed studies of the mineralogy, alteration, and fluid inclusions of the Lake George deposit have been carried out by Watson (1981), Scratch et al. (1984), and Seal (1984). There is a general consensus among these authors that the scheelite mineralization was related to the emplacement of the granodiorite stock. Fluid inclusion data of Seal (1984) suggest that the scheelite-bearing assemblage was deposited by brines of moderate salinity at temperatures between 550° and 175°C. Two models have been presented for the genesis of the stibnite-bearing quartz veins (Scratch et al. 1984). They concluded that the veins formed between 325° and 350°C from a boiling solution at a depth of approximately 1.5 km below the prevailing water table. They suggested that the monzogranite intrusion produced the fracture system and caused convection of connate seawater that leached antimony and gold from previously enriched shales. The highly anomalous antimony content in the slates supports their model of prior enrichment of these rocks. The hematitic alteration zone was considered the recharge area for the hydrothermal cell. Their second model suggests hydrothermal fluids were generated during crystallization of a magma that had been enriched by assimilation of country rock. In the latter case, the hematitic alteration zone is considered to represent the encroachment of groundwater on the juvenile hydrothermal system.

Scheelite-bearing stringers similar to those found at Lake George also occur in the Coac Stream area (26) north of the Saint John River and along a prominent fault in the Pendar Brook area (46) in the northeastern St. Croix Terrane. A rather uncommon occurrence is along the northeast contact of the Pokiok

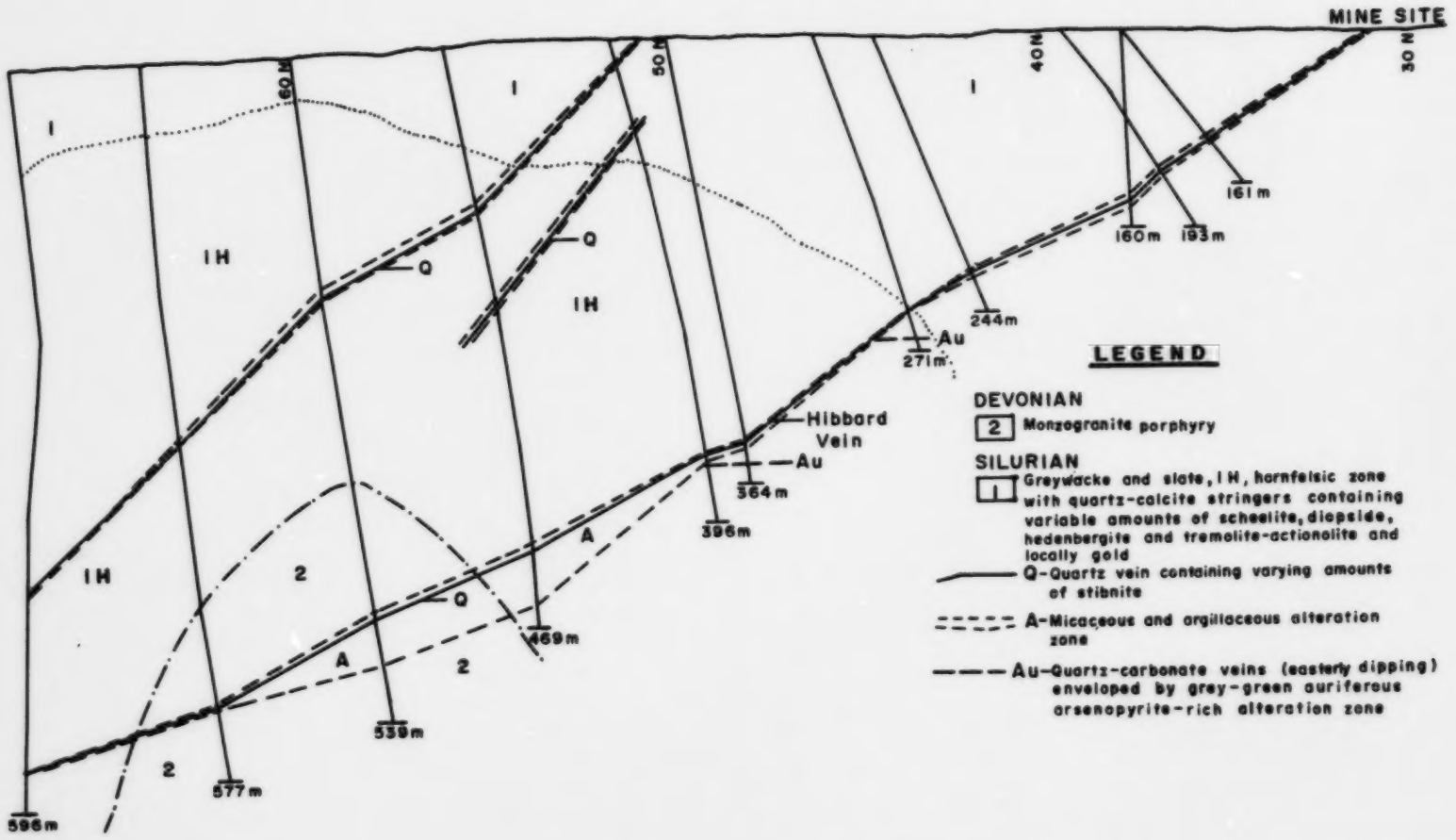


Figure 6. North-south section through the Lake George antimony-gold-tungsten deposit. See Figure 2, number 28 for location of deposit.

Batholith at Zealand Station (25), where disseminated molybdenite occurs with abundant beryl in quartz-orthoclase pegmatite.

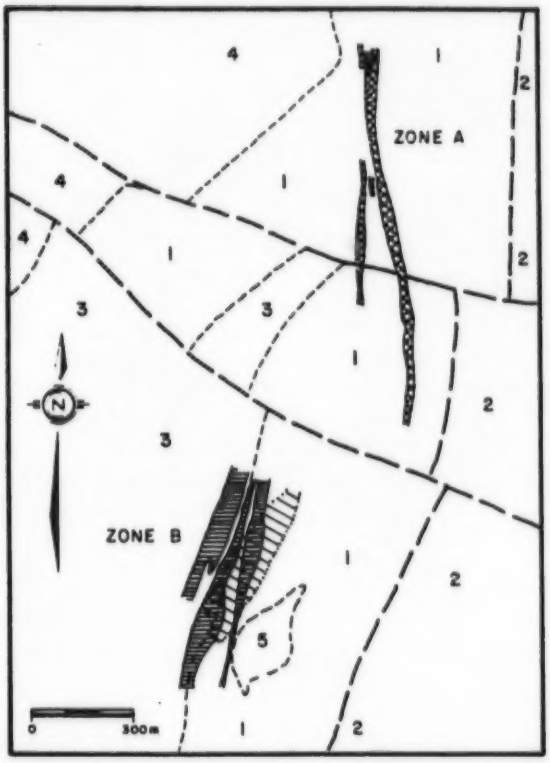
Gold, with or without arsenopyrite, also occurs in the contact aureoles of Devonian mafic and felsic plutons that intrude Lower Ordovician pelitic sedimentary and mafic volcanic rocks in the Waweig Stream area (31) in the St. Croix Terrane. The veins occur along the crests of steep-plunging cross folds and in dilatant shear zones (Ruitenberg 1967).

The Jimmy Hill and Otter Lake South gold-bearing quartz-carbonate vein systems (48) were discovered recently in the northeastern St. Croix Terrane. The Jimmy Hill veins cut across a roof pendant composed of hornfelsed greywacke and slate in the Early Devonian Magaguadavic Granite. The veins are up to 30 cm wide and contain dark grey quartz with pyrite and, locally, wolframite crystals up to 3 cm in diameter and disseminated bismuthinite grains up to 1 cm in diameter; the wolframite is, in places, altered to scheelite. Fine-grained, visible gold and traces of molybdenite have also been observed; one assay from a grab sample yielded 5.9 g/t Au (Ruitenberg et al. 1989). At Otter Lake South, the quartz-carbonate veins are hosted by similar metasedimentary rocks that are intruded by quartz-feldspar porphyry dykes and altered in part to chlorite, hematite, and illite. The veins strike northwesterly, dip steeply, and contain pyrite, pyrrhotite, chalcopyrite, bismuthinite, stibnite, arsenopyrite, silver minerals, and gold; grab samples contain up to 3.9 g/t Au (Ruitenberg et al. 1989).

The Sisson Brook tungsten deposit (16) occurs in the thermal aureole of the Devonian Nashwaak pluton along its contact with regional amphibolite-grade metamorphic rocks of Early Paleozoic age (Lutes 1981; Ruitenberg and McCutcheon 1985b; Fyffe et al. 1988). A porphyritic biotite granite stock was delineated near the deposit by diamond drilling. The deposit is composed of two mineralized zones (Figure 7): Zone "A" to the north consists of two steep-dipping, 10 to 80 m wide, north-northwest-trending vein- and quartz-stockwork-filled fracture zones in Lower Paleozoic felsic and mafic metavolcanic and metasedimentary rocks. Zone "B", to the south, consists of several north-northeast-trending tungsten-bearing zones transected by a molybdenum-rich zone and hosted mainly by gabbro. The metallic minerals are generally fine-grained (H.J. Nast and A.E. Williams-Jones, written communication, 1984).

The zones contain several types of vein sets from youngest to oldest (1-5) respectively consisting of: (1) scheelite and molybdoscheelite within bright green amphibolite-rich veins, fractures and massive clasts 1 to 5 cm across (Zone B only); (2) thin scheelite ± sulphide-bearing quartz ± biotite stringers; (3) scheelite (Zone B only) ± molybdenite ± pyrrhotite in quartz veinlets; (4) quartz stockwork with fractures containing wolframite, chalcopyrite, pyrrhotite ± molybdenite (Zone A); and molybdenite ± scheelite ± minor wolframite, chalcopyrite and/or pyrrhotite (Zone B); (5) pyrite ± arsenopyrite ± trace chalcopyrite ± trace molybdenite in carbonate ± trace fluorite veins, fracture-fillings, and pervasive, massive carbonate flood zones.

Nast and Williams-Jones (written communication, 1984) distinguished three alteration mineral assemblages in Zone A and four in Zone B. The oldest assemblage (a) occurs primarily in the gabbro and is intimately associated with the early scheelite in Zone B. Younger alteration mineral assemblages chronologically



LEGEND

1 Late Precambrian or Early Paleozoic volcanic and sedimentary rocks

2 Cambrian quartz wacke

3 Devonian gabbro and granodiorite

4 Devonian Nashwaak Granite

5 Devonian porphyritic granite

------- geologic boundary

—— —— fault

mainly wolframite-chalcopyrite ore

mainly scheelite-sphalerite ore

mainly molybdenite-scheelite ore

Figure 7. Geology of Sisson Brook tungsten deposit (H.J. Nast and A.E. Williams-Jones, written communication, 1984; S. Enns, written communication, 1984).

designated here as (b), (c), and (d) occur in both zones A and B. These assemblages are characterized as follows:(a) in Zone B consists of bright green, iron-rich amphibole with or without albitized plagioclase and potassium feldspar; (b) iron-rich biotite genetically related to the development of a late crenulation cleavage; (c) sericite and quartz associated with the more intensely metallized parts of Zone A and the molybdenite-bearing rocks in Zone B; (d) carbonate and sericite with or without minor chlorite, epidote, pyrite, and/or arsenopyrite.

DEPOSITS RELATED TO HIGH-SILICA GRANITES

Silica- and alkali-rich granites occur as a cluster of plutons in the Burnthill area of central New Brunswick, as part of the Saint George Batholith in southern New Brunswick, and as satellite stocks along the northern boundary of the Saint George Batholith. These Late Silurian to Late Devonian granites have features similar to A-type granites (Loiselle and Wones 1979; Rogers and Greenberg 1981; Collins et al. 1982; Whalen 1986). Three

distinct types of deposits are associated with these plutons: contact metasomatic base metal deposits in the Mascarene Belt; base metal sulphide veins associated with Late Silurian peralkaline granitic rocks in the Mascarene Belt; and tungsten-molybdenum-tin deposits associated with Middle to Late Devonian silica-rich and subalkaline granites in the central Miramichi and St. Croix terranes.

These peralkaline and silica-rich subalkaline granites contrast markedly with the granodioritic (I-type characteristics) intrusions in the Matapédia Belt and biotite- and muscovite-bearing granites (mixed I- and S-type affinities) of the Miramichi Terrane (Gander Zone). The Welsford Complex (McLeod 1991) is an east-northeast-trending body of peralkaline granite, quartz syenite, and granophyre that is truncated to the west by the Mount Douglas pluton. The peralkaline granite contains sodium-rich amphiboles and pyroxenes and various rare-earth minerals, and is enriched in Zr, Nb, Y, and Rb (Payette and Martin 1987, 1988). Biotite granites associated with tungsten-molybdenum-tin deposits at Mount Douglas and in the Burnthill Brook area are silica-rich and slightly peraluminous subalkaline (Ruitenberg and Fyffe 1982; MacLellan and Taylor 1989). They are also characterized by very high K_2O/Na_2O, Rb/Sr, and Rb/Ba, and low Fe, Mg, and Ti. F and Ce contents of these granites are also found to be high - a feature characteristic of some A-type granites (Collins et al. 1982; Rogers and Greenberg 1981). The Sn and W contents of the granitic stocks that host deposits of economic interest vary from 3 to 55 ppm. Magmas that gave rise to these types of intrusions are interpreted to have been formed by partial melting of lower crustal material depleted in water (Collins et al. 1982).

Contact Metasomatic Base Metal Deposits

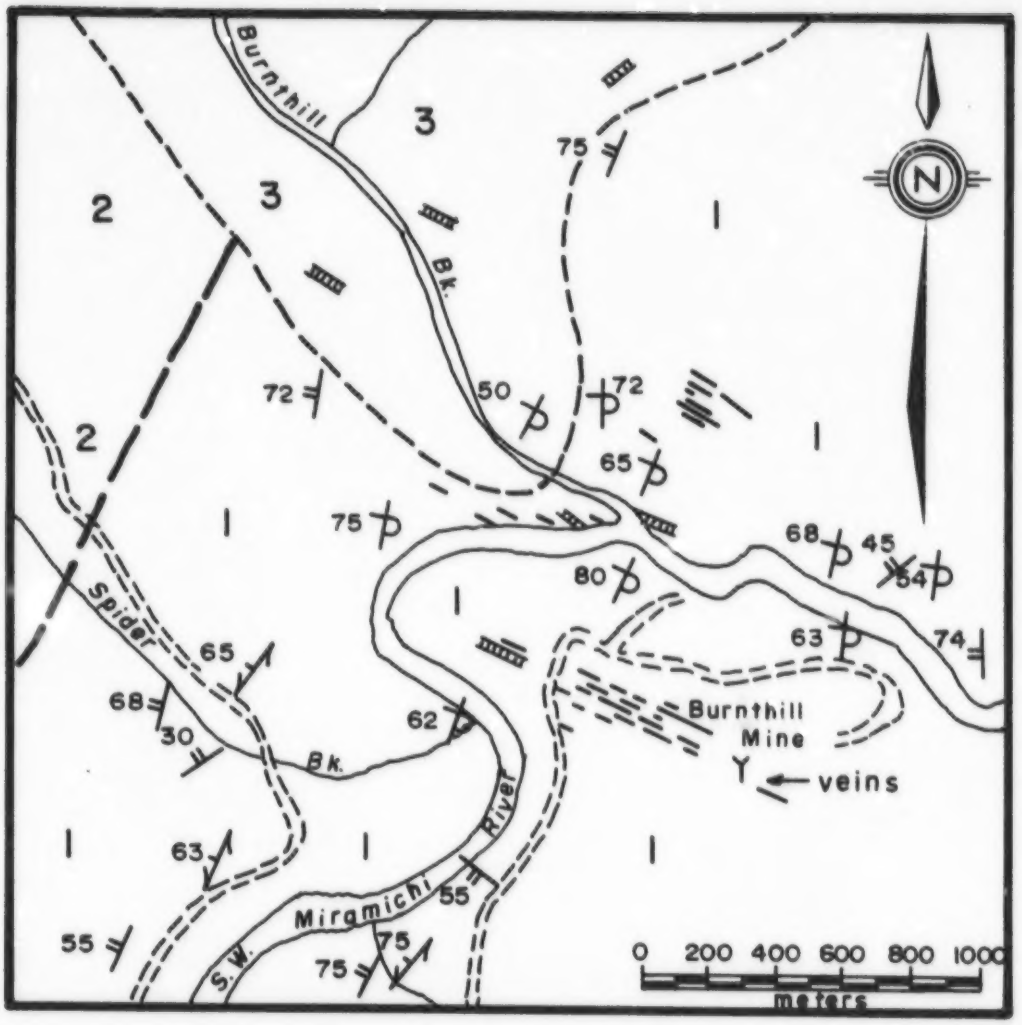
The only known contact metasomatic base metal sulphide occurrence in southern New Brunswick is associated with the Upper Devonian Mount Douglas Granite at Nerepis (42) in the Mascarene Belt (Ruitenberg 1969). Pods and small lenses of pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, and tin minerals occur in a siliceous garnetiferous skarn zone in Upper Silurian calcareous sedimentary rocks.

Base Metal Sulphide Veins

Typical base metal sulphide veins and breccia fillings are associated with northwest-trending faults that cut the peralkaline Welsford Complex at Reserve Brook (43) and Johnson Croft (44) in the southeastern Mascarene Belt. Sphalerite, argentiferous galena, minor chalcopyrite, tetrahedrite, siderite, and quartz occur as irregular veins and pods in shear zones and breccias along the contact of the complex (Ruitenberg 1970; McCutcheon and Ruitenberg 1987).

Tungsten-Molybdenum-Tin Deposits

One of the most extensively explored tungsten-molybdenum-tin deposits in the Miramichi Terrane is the Burnthill deposit (17). It consists of numerous tungsten-, molybdenum- and tin-bearing greisen veins associated with the Middle Devonian Burnthill Granite (Victor 1957; Potter 1969; Ruitenberg and McCutcheon, 1985b) (Figures 8 and 9). The Burnthill pluton and several others to the east (Rocky Brook, Sisters Brook, Trout Brook, and Dungarvon) occur just to the south of the dextral Catamaran Fault (Figure 2). Varying proportions of



LEGEND

1 Cambrian-Ordovician quartzite

2 Ordovician lithic wacke

3 Upper Devonian or Lower Mississippian biotite granite

geologic boundary

fault

bedding (tops unknown, overturned)

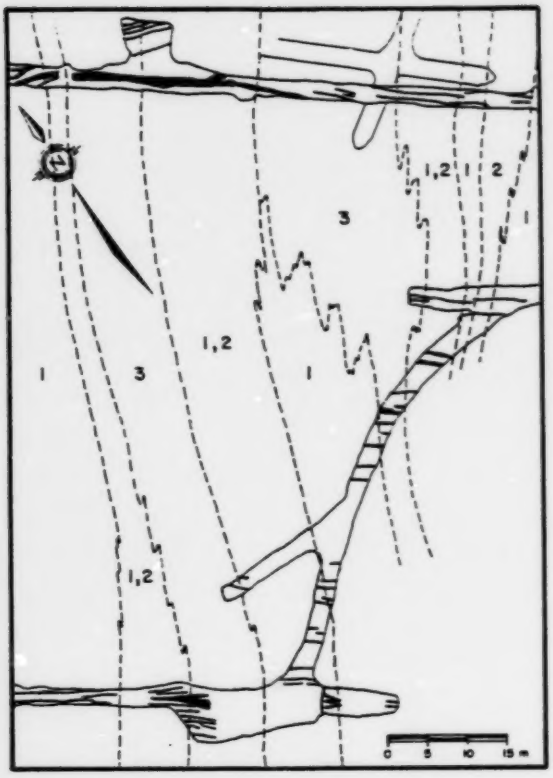
cleavage

quartz-topaz veins with W, Mo and Sn

quartz-muscovite veins with W, Mo and Sn

mine adit portal

Figure 8. Geology of Burnthill mine area (after Potter 1969; Crouse 1981). See Figure 2, number 18 for location of deposit.



LEGEND

ORDOVICIAN

1 Massive and thick-bedded argillite

2 Quartzitic argillite and argillaceous quartzite

3 Quartz wacke

tungsten-molybdenum-tin-bearing quartz veins.

Figure 9. Underground geology of part of the Burnthill tungsten deposit (N.E. Brewster, written communication, 1975). For location see mine adit portal in Figure 8.

four texturally distinct units, mainly composed of biotite granite, were identified within each pluton. The oldest is a porphyritic, generally hornblende-bearing melanocratic unit with less modal quartz and alkali feldspar and more plagioclase and biotite than the younger units and occurs as roof pendants. The most extensive unit is composed of coarse-grained, seriate biotite granite with an allotriomorphic seriate groundmass. The coarse-grained unit both grades into, and is intruded by medium- to fine-grained equigranular biotite granite. Dykes of porphyritic microgranite and pods of pegmatite form the youngest unit (MacLellan and Taylor 1989).

The numerous W-Sn-Mo-Be-Fe-bearing quartz veins of the Burnthill deposit occur within the apical portion of a cupola on the southern margin of the Burnthill pluton, and in the overlying quartz wacke and argillaceous metasedimentary rocks of the Miramichi Group. The vein swarms strike southeasterly, parallel to a prominent joint set and dip steeply (Figure 8). They pinch and swell both vertically and horizontally, and are commonly branching and anastomosing. Individual veins vary in width from about 2 cm to 2 m and are commonly spaced from about 5 cm to several metres apart. Potter (1969) distinguished two types of ore-bearing veins at Burnthill: (a) those with quartz, muscovite, minor beryl, molybdenite, wolframite, fluorite, scheelite, and cassiterite; and (b) those with quartz, topaz, minor wolframite, pyrrhotite, chalcopyrite, pyrite, arsenopyrite, fluorite, sphalerite, molybdenite, beryl, and cassiterite. The various metallic minerals in the veins tend to cluster

in coarse multi-mineralic pods with only a few mineral species in any given pod.

At Tin Hill (18), coarse cassiterite crystals (up to 2 cm in diameter), wolframite, magnetite, and pyrite occur in quartz veins along the western contact of the coarsely porphyritic granite cupola on the southeastern margin of the Burnthill pluton (Richardson 1981). At Two and a Half Mile Brook (19), cassiterite- and wolframite-bearing quartz veins occur in quartz wacke and siltstone in the thermal aureole of the Burnthill pluton (Crosby 1984). Similar tungsten-tin-bearing veins occur at Todd Mountain (20) in the thermal aureole of the Trout Brook Granite (Wright 1940). At Sisters Brook (23), cassiterite + arsenopyrite ± wolframite ± molybdenite in quartz-chlorite and quartz-muscovite veins up to 20 cm wide occupy a 25 m wide zone in cordierite-bearing hornfels that overlies a granite cupola. At Falls Brook and Rocky Brook (21), narrow greisen veins with cassiterite and hematite cut across medium-grained, porphyritic granite.

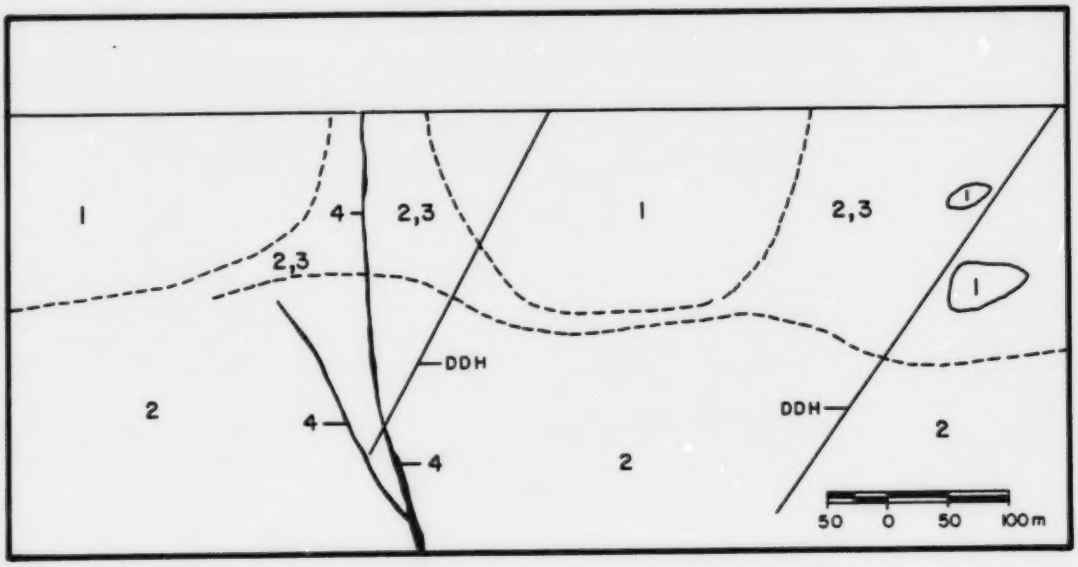
The endogranitic Little Dungarvon River showing (22) comprises an extensive zone of disseminated cassiterite in fine-grained equigranular granite of the Dungarvon pluton; some coarser cassiterite crystals line miarolitic cavities in the granite (Gardiner 1985). At Four Mile Brook to the southwest of the Little Dungarvon showing, high grade, narrow, tin-bearing veins cut across medium-grained biotite granite. The veins consist of feldspar, quartz, cassiterite, fluorite, and beryl, and are associated with hematitic and potassic alteration. The cassiterite crystals exhibit dark brown unzoned cores enveloped by honey-coloured zoned rims.

In southwestern New Brunswick, tin-, tungsten-, and molybdenum-bearing greisen deposits occur mostly in and around the contact of the Late Devonian Mount Douglas granite (37, 38, 40, 41), which forms the eastern portion of the Saint George Batholith. Wolframite- and molybdenite-bearing quartz veins in the Deer Lake area (39) that cut Ordovician and/or Silurian sedimentary rocks could be associated with late felsic phases of the Devonian Magaguadavic granite. The Mount Douglas granite is composed of three texturally and, in part, mineralogically distinct units (McCutcheon and Ruitenberg 1987; McLeod et al. 1988; McLeod, 1990). From oldest to youngest these are: Unit 1, coarse- and medium-grained, seriate rapakivi granite and associated porphyritic microgranite; Unit 2, coarse- to fine-grained, seriate biotite granite; and Unit 3, medium-grained, equigranular biotite granite, and porphyritic microgranite. The linear distribution of this latest phase along projections of a major northeast-trending fault indicates a strong structural control on granite emplacement and vein distribution. Sheeted greisen vein systems are mainly concentrated in the Mistake Lake (37), Victoria Lake (38), and Square Lake (41) areas and are best developed near the intrusive contact of Unit 3 and Unit 2 (McLeod et al. 1988; McLeod 1990). The vertical, parallel veins, up to 2 cm in width, with an associated altered granite envelope up to 50 cm in width, are emplaced in extension fractures that exhibit a well-defined preferred orientation at 085° and subordinate orientations of 120° and 025°.

Tin, tungsten, and molybdenum deposits are associated with several satellite intrusions of Late Devonian to Early Carboniferous age, along the northern margin of the Saint George Batholith, including in particular the Mount Pleasant subvolcanic complex. Small amounts of tungsten, tin, and molybdenum minerals occur in a stock of microgranite in the Pleasant Ridge area (32), west of Mount Pleasant. A prominent,

northwest-striking, steeply dipping fracture zone, about 3 m wide, contains a vein system composed of chlorite, hematite, magnetite, iron sulphide, and tin minerals. The veins, which cut across wacke and slate of the Digdeguash Formation, tend to be thicker in the wacke than in the slate.

The True Hill deposit (33) is associated with three granite porphyry cupolas that reach the surface and are aligned in a north-northeasterly direction within wacke and slate; only two are located within the area of Figure 10. Moderate to intense greisenization affected the apical parts of the cupolas, and hydrothermal pebble breccias and breccia dykes are developed locally along their flanks. In places, near the top of the cupolas, a contact breccia is developed between the granite porphyry and the sedimentary host rocks. The breccias at True Hill resemble those of the subvolcanic Mount Pleasant deposit (Ruitenberg 1967; Lentz et al. 1988). Two types of mineral assemblages are present in the True Hill deposit: disseminated tungsten, molybdenum, and bismuth minerals; and tin-sulphide lodes. The disseminated type is hosted by greisen in both granite and adjacent metasedimentary rocks. The tin-sulphide lodes occur mainly in the granite porphyry where they follow faults, joints, and porous greisenized granite. The principal minerals are cassiterite, sphalerite, chalcopyrite, galena, stannite, and native silver together with pyrite, iron-manganite, chlorite, quartz, and fluorite. Lodes in the metasedimentary rocks also contain schorl



LEGEND

1 Upper Silurian metasediments (Waweig Formation)

2 Granite porphyry

3 Greisen

4 Tin-sulphide lodes

Figure 10. Section through the True Hill tin-tungsten deposit (after D. Lentz, written communication, 1984). See Figure 2, number 33 for location of deposit.

and rutile.

The Mount Pleasant deposits (34) are situated along the western margin of the Mount Pleasant caldera (Ruitenberg 1967; McCutcheon 1984, 1990). Tungsten-molybdenum and tin ± base metal sulphides are spatially associated with, respectively, early fine-grained granite and younger granite porphyry intrusions. These intrusions were emplaced in the Late Devonian volcanic sequences in two areas (Kooiman et al. 1986; Sinclair et al. 1988) referred to as the North and Fire Tower zones (Figures 11 and 12). The oldest volcanic unit at Mount Pleasant is quartz-feldspar porphyry, which overlies and locally intrudes fine-grained Upper Silurian wacke and slate. The Silurian rocks are commonly intensely brecciated in the contact zone with the quartz-feldspar porphyry. Feldspar porphyry overlies and locally intrudes the quartz-feldspar porphyry in the North Zone and in the area between the North and Fire Tower zones. The feldspar porphyry and quartz-feldspar porphyry are intruded by the fine-grained granite and granite porphyry and associated dykes. Hydrothermal breccias associated with emplacement of the ore deposits contain some or all of the following clasts: quartz-feldspar porphyry, feldspar porphyry, and fine-grained granite. In places, flow-banded porphyry intrudes the breccia and locally is affected by later brecciation and silicification (Ruitenberg 1967; Sinclair et al. 1988).

Detailed investigation of the Mount Pleasant Fire Tower orebody by Kooiman et al. (1986) showed that greisenized breccias that host the porphyry tungsten-molybdenite deposits grade downward through microgranite breccias into a stockwork-veined granite porphyry. Two distinct types of tin deposits are related to the granite porphyry: (1) tin-base metal veins and replacement bodies that are superimposed (in the higher levels) on the tungsten-molybdenum deposits; (2) endogranitic tin- and relatively minor base-metal-sulphide-bearing greisen form irregular bodies at lower levels within the granite porphyry. The mineralogy of the tungsten-molybdenum deposits is characterized by wolframite, molybdenite, native bismuth, bismuthinite, arsenopyrite, and loellingite. The tin-base metal ores comprise an assemblage of cassiterite, sphalerite, galena, arsenopyrite-loellingite, pyrite, stannite, tennantite, tetrahedrite, and bornite (Ruitenberg 1963, 1967; Boorman 1968; Petruk 1964, 1973). The main alteration minerals are quartz, fluorite, topaz, and chlorite. Greisenization and accompanying tungsten-molybdenum mineralization in the Fire Tower Zone was associated with the exsolution of high-salinity (30 equivalent weight % NaCl), fluorine-rich aqueous fluid from the granite porphyry (Davis and Williams-Jones 1985; Samson et al. 1985). Homogenization temperatures of inclusions range from 200° to 490°C. Secondary vapor-rich inclusions are common, indicating boiling related to a pressure decrease. The secondary inclusions can also reflect cooling and a pressure drop during exsolution of a supercritical magmatic fluid.

Tungsten-molybdenum deposits in the North Zone comprise extensive mineralized fracture zones in breccia and granite. Wolframite, molybdenite, bismuth, bismuthinite, arsenopyrite, and loellingite are the most abundant minerals. A variety of tin deposits that post-date the tungsten-molybdenum mineralization formed at different levels within the North Zone. Near-surface, sulphide-rich replacement deposits are hosted by altered feldspar porphyry and associated banded quartz-feldspar porphyry dykes, both of which are intensely fractured and brecciated (Ruitenberg 1967). In these deposits, fine-grained cassiterite and less common stannite occur with

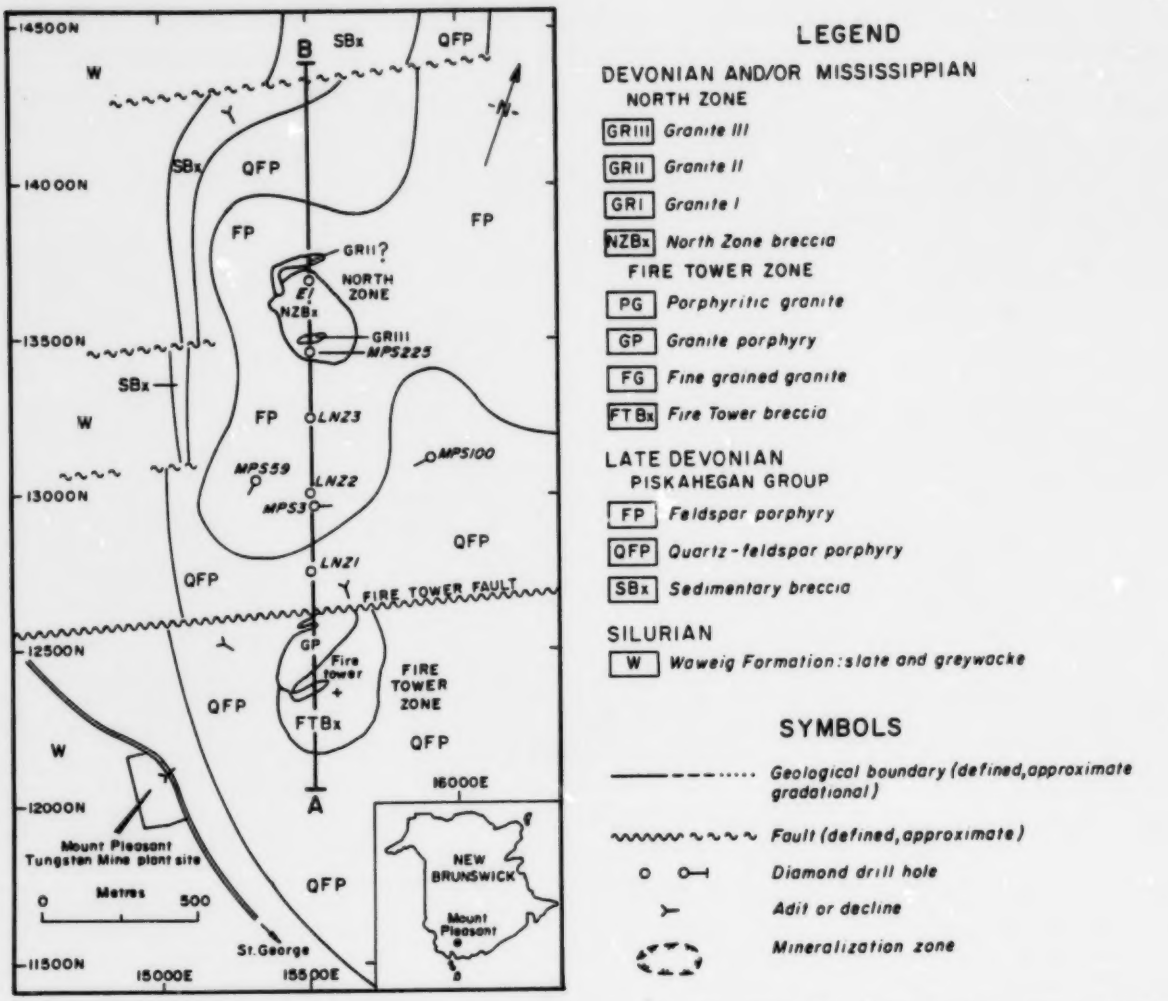


Figure 11. Geology of Mount Pleasant deposit (modified from Ruitenberg 1967 and McCutcheon 1983). See Figure 2, number 34 for location of deposit.

abundant arsenopyrite, loellingite, sphalerite, and chalcopyrite, and lesser amounts of pyrite, marcasite, galena, molybdenite, tennantite, bornite, bismuthinite, wittichenite, and roquesite. Quartz, fluorite, topaz, and chlorite are the principal gangue minerals. Most of the potentially economic tin deposits in the North Zone are found at deeper levels between 200 to 400 m (Sinclair et al. 1988) (Figures 11 and 12). The total tin reserves in the North Zone are 5 900 000 tonnes averaging 0.79% Sn; tungsten-molybdenum reserves in the North Zone are approximately 11 500 000 tonnes grading 0.20% W, 0.06% Mo, and 0.09% Bi (The Northern Miner, October 14, 1985).

Greisenized breccias have also been intersected by diamond drilling in the McNamara prospect (36) along the northeast margin of the Mount Pleasant caldera and are exposed at the surface in the Mud Lake area (35) immediately northeast of Mount

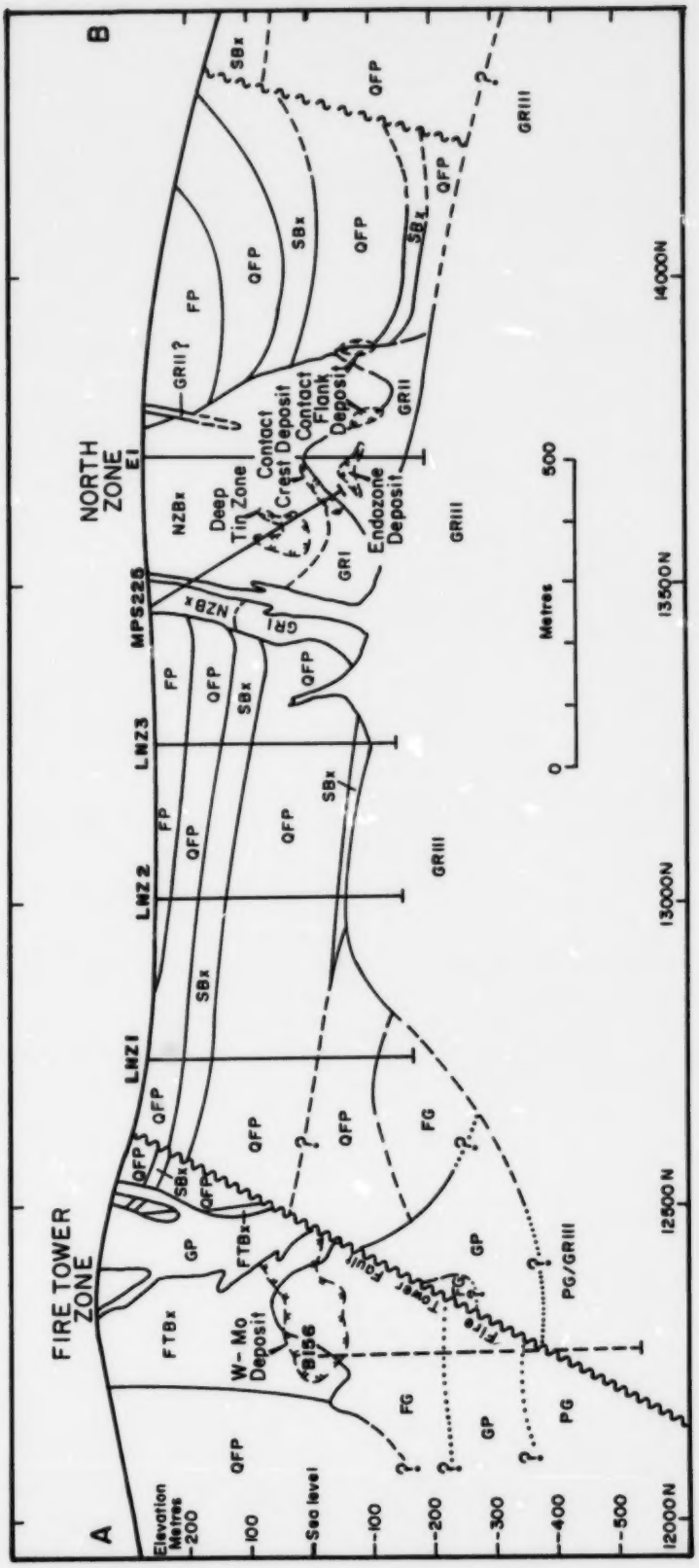


Figure 12. Cross-section A-B through the Mount Pleasant area (after Sinclair et al. 1988). See Figure 11 for location and legend.

Pleasant. Uraniferous, subvolcanic breccias of Early Carboniferous age occur in the Harvey area (29).

SUMMARY AND CONCLUSIONS

Several distinct types of metallic mineral deposits are associated with various plutonic rocks in the New Brunswick Appalachians. These plutons were emplaced mainly during successive episodes of terrane accretion that occurred between Silurian and Devonian times. Subvolvanic intrusions of intermediate to felsic composition tend to be more abundant in the Elmtree Terrane and Matapédia Belt, whereas the felsic plutons of batholithic proportions are more common in the Miramichi and St. Croix terranes, generally reflecting a greater depth of emplacement. Layered mafic intrusions occur locally in the St. Croix and Miramichi terranes.

Deposits associated with subvolcanic calc-alkaline Siluro-Devonian intrusions, (I-type characteristics) include contact metasomatic, vein-type base metal sulphide deposits and porphyry-copper-molybdenum-gold deposits. Williams-Jones (1982) concluded from a study of the Patapedia contact metasomatic deposit that the hydrothermal system that generated the metallization was produced by calc-alkaline intrusions. The sequence of alteration events associated with the deposit is similar to a porphyry system. The common spatial association of the vein and contact metasomatic deposits suggests that they are genetically related. Most porphyry copper-molybdenum-gold deposits in New Brunswick have characteristics of shallow emplacement such as miarolitic cavities and explosion breccias. The Benjamin River copper-bearing porphyry in the norcheastern Matapédia Belt is hosted by granodiorite that is presumably comagmatic with the surrounding Silurian volcanic rocks. Similarly, the porphyry-copper deposit within granodiorite at Connell Mountain are likely related to nearby Ordovician Tetagouche volcanic rocks of the Miramichi Terrane.

Several types of deposits are associated with an extensive family of bimodal batholithic intrusions. The antimony-gold-tungsten deposits at Lake George are associated with the Siluro-Devonian Pokiok Batholith, which has mixed I- and S-type characteristics. The early scheelite-gold-bearing quartz-chlorite veins occur at Lake George in the contact aureole of a small monzogranite stock adjacent to the batholith, whereas the younger antimony-gold deposits cut across the stock. Tungsten-molybdenum veins are also associated with a late phase of the Nashwaak pluton, northeast of the Pokiok Batholith. Base metal veins of the Long Lake deposit are associated with porphyry dykes that constitute the youngest intrusions of the North Pole Stream pluton. The Nashwaak, Pokiok and North Pole Stream plutons are likely, in large part, to have formed from partial melting of a tectonically thickened Cambrian-Ordovician continental rise prism and underlying Precambrian continental basement. Lack of associated volcanic rocks and extensive contact aureoles suggest emplacement at relatively deeper levels.

Late Devonian silica-rich granites with some A-type features contain tungsten-molybdenum-tin deposits and were emplaced at shallow depth. Some, such as those at Mount Pleasant, are associated with terrestrial subvolcanic complexes. The deposits hosted by these granites are mainly exo- and endogranitic greisens rich in fluorine. Petrochemical studies suggest that these subalkaline granites originated from late stage decompressional partial melting of lower crust that had become depleted in water during earlier continental collision.

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